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THE EFFECTIVENESS OF VARIOUS LOCAL SHIELDING ARRANGEMENTS ERECT--ETC(U)
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DEPARTMENT OF NATIONAL DEFENCE
CANADA

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE NO. 79-20

THE EFFECTIVENESS OF VARIOUS LOCAL SHIELDING ARRANGEMENTS ERECTED NEAR THE TARGET OF THE DREO NEUTRON GENERATOR IN REDUCING THE BIOLOGICAL HAZARD AT SPECIFIC LOCATIONS ON THE DREO SITE

by

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SEPTEMBER 1979
OTTAWA

ABSTRACT

The effectiveness of various forms of shielding near the target of the neutron generator in reducing the dose rate at specific locations on the DREO site has been investigated. It would appear possible to satisfy AECB requirements so far as reducing the dose rate along the perimeter fence bordering the railway right-of-way is concerned, but substantial additional shielding would be required to reduce the dose rate significantly at the nearest occupied building, Building 14. In the latter case, to take advantage of the maximum operating hours permitted by the licence, AECB requirements could be met only by construction of a massive shield around the target, otherwise the cumulative dose inside Building 14 could be monitored and operations terminated when the total dose reached the permitted yearly limit for non-atomic workers.

RÉSUMÉ

Une étude a été faite sur l'efficacité des diverses formes de blindage situées prés de la cible du générateur de neutrons et servant à réduire le dosage dan des endroits particuliers sur l'emplacement du CRDO. Il semble possible de répondre aux exigences de la CCEA en ce qui a trait à la réduction du dosage le long du périmètre de al clôture longeant le chemin de fer; cependant, pour réduire de façon appréciable le dosage à l'édifice voisin, soit le bâtiment 14, it faudrait ajouter une quantité considéralbe de blindage. Dans le présent cas afin de tirer parti, au maximum des heures d' exploitation autorisées par le permis, il nous faudrait, pour répondre aux attentes de la CCEA, construire un blindage massif autour de la cible, sinon il faudra contrôler le dosage cumulatif à l'intérieur de l'édifice 14 et l'exploitation devra être interrompue lorsque le dosage total aura atteint la limite annuelle permise pour les employés qui no sont pas attachés aux travaux atomiques.

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1. INTRODUCTION

The DREO 150-keV Texas Nuclear Neutron Generator is situated in an open-field location where it is shielded from occupied buildings on the site by an L-shaped concrete-block wall and where the surrounding area is enclosed by a protective perimeter fence. On the basis of a previous radiation survey of the DREO site (1), for the case of a 14-MeV neutron output of 10^{10}n/s, the Atomic Energy Control Board expressed concern that the dose rate at the entrance of the nearest occupied building, Building 14, was of the order of the maximum rate to which non-atomic workers should be exposed at any time. The Board was also concerned that the dose rate at the perimeter fence along the railway right-of-way, which was in direct view of the target of the neutron generator, was much in excess of this maximum.

In its subsequent biennial review of the operating licence of the generator the Board imposed a number of specific conditions to which renewal of the licence was subject. Thus, for a 14-MeV neutron output of not more than $3\text{-}4 \times 10^9$ n/s, suitable additional shielding, acceptable to the Board's Directorate of Licensing, was to be installed in the vicinity of the target in order to reduce the dose-equivalent rate at Building 14. In other cases, where outputs of up to 10^{10} n/s would be required, a shadow shield was also to be erected between the target and the railway tracks, and a complete radiation survey was to be carried out to assess the effectiveness of the shield before further operation at such output levels would be sanctioned. In addition, it was requested that the effect, if any, of this shadow shield on the radiation level at the entrance to Building 14 be determined.

The present report describes the results of the radiation survey which was carried out in compliance with the above-mentioned directives. In order to assess the effectiveness of any shield which would be erected, a detailed neutron survey was first carried out over a measured grid within the perimeter fence and at certain locations elsewhere before any additional shielding was put in place near the target. Then the effect of a number of different shielding configurations on the dose rate at various grid points was determined including, in particular, those along the fence bordering the railway, and measurements were also made at the entrance to Building 14.

Details of the layout of the field installation, together with the locations of the grid points at which survey measurements were made, are shown in Figure 1.

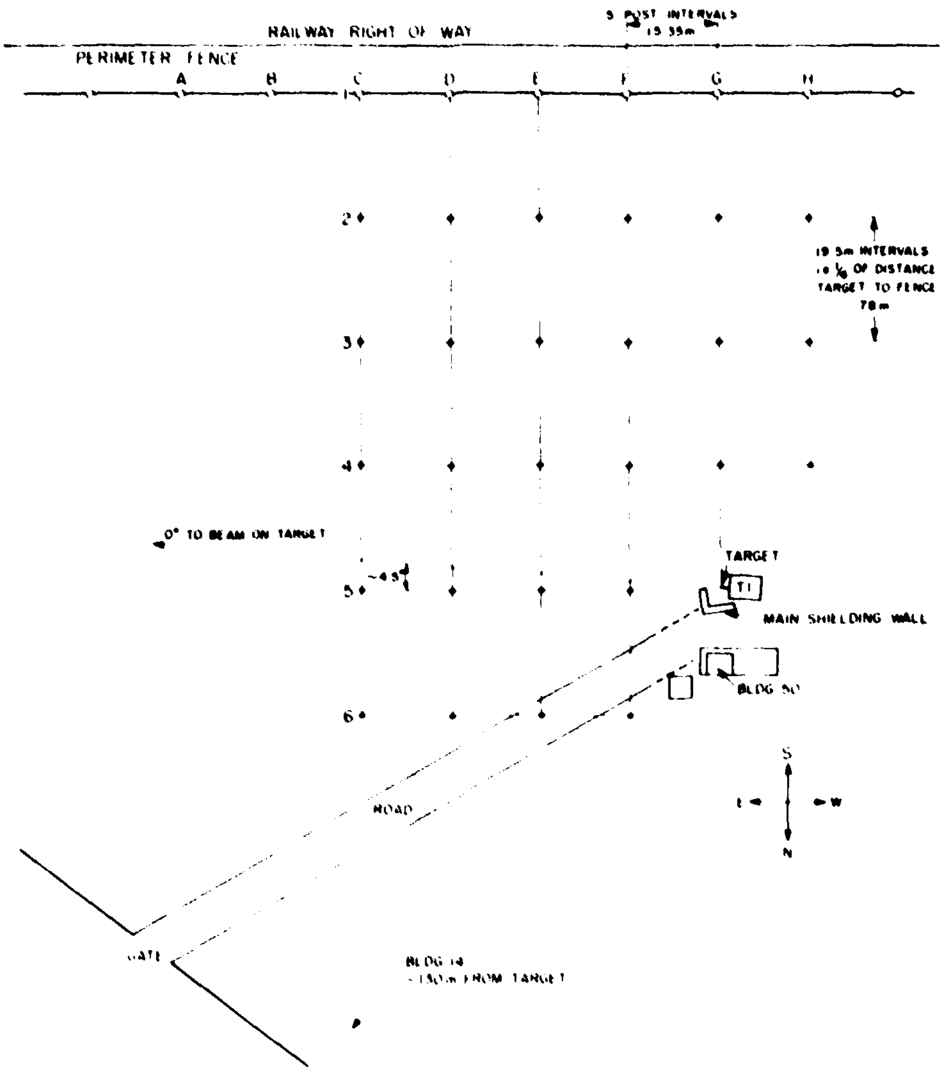

Figure 1

Details of the layout of the Neutron Generator field installation, showing locations of the grid points at which survey measurements were made. The Neutron Generator itself is located in Building T1.

2. RADIATION SURVEY TECHNIQUES

The radiation survey was carried out using an Eberline portable, battery operated, Neutron Rem Counter, Model PNR-4, the output of which was recorded from the phone connector by means of a scaler (Ortec Model 772). Since this survey was carried out mainly under winter conditions, over snow-covered terrain, the scaler and its associated power-supply bin were mounted on a toboggan, together with a Honda Model EG1500 gasoline-powered generator to supply ac power. Figure 2 shows this mobile detection system in position at one of the grid markers. For most of those measurements which were carried out during cold weather the Rem counter, which consisted of a 22.86-cm (9-inch) diameter cadmium-loaded polyethylene sphere with a BF_3 tube in the center and an attached electronics module, was enclosed in a 2.54-cm (1-inch) thick insulating foam styrene cover which contained an electric light bulb of a suitable size, depending on external ambient conditions, to maintain the temperature of the assembly above 0°C. Because of small variations in speed of the engine of the generator, the frequency of the voltage output was not sufficiently constant to permit accurate electronic timing of counting intervals, and a stop-watch was therefore employed for this purpose. In the few cases were mains power was available and could be used in place of the generator, a Model 719 Ortec Timer was used to time the counting period.

Calibration of the Rem counter was carried out using a standard Pu-Be source, and the output of the neutron generator was monitored by means of a fission chamber whose calibration factor was established by suitable techniques. This monitor was sufficiently close (40 cm at 162°) to the generator target that neutrons scattered from any shielding which would be erected in the vicinity would not be expected to make a significant contribution to the total number detected, and thus determination of the target output would not be adversely affected.

3. INITIAL REFERENCE SURVEY

3.1 Measurements

Dose-rate measurements were made during the winter (January-February 1978) at nearly all of the grid points shown in Figure 1, and also at the gate of the perimeter fence and at the entrance to Building 14. Measurements at some locations near the target and at Building 14 were repeated later (April-May) after the snow had disappeared, and some additional measurements were also made at this time. The unshielded target of the neutron generator, as employed for these measurements is shown in Figure 3A.

On the basis that the output of the $T(d,n)^4He$ reaction is essentially isotropic (within ~11%) in the laboratory system (2), the results of all these measurements can be most clearly and graphically summarized by means of a plot of the response of the Rem counter at a particular grid point versus the inverse square of the distance of that grid point from the target. Such a plot is shown in Figure 4, where some of the points are labelled with the particular grid locations at which the measurements were made. In this figure two scales are provided for the ordinate axis. The left-hand scale denotes the counts recorded

Figure 2

Mobile detection system in position at grid marker No.

Figure 5A

The unshielded target of the neutron generator. The fission-chamber monitor can be seen fastened to the strut which supports the beam tube. The 6 x 6 cement-block array is auxiliary shielding between the target and the main L-shaped shielding wall.

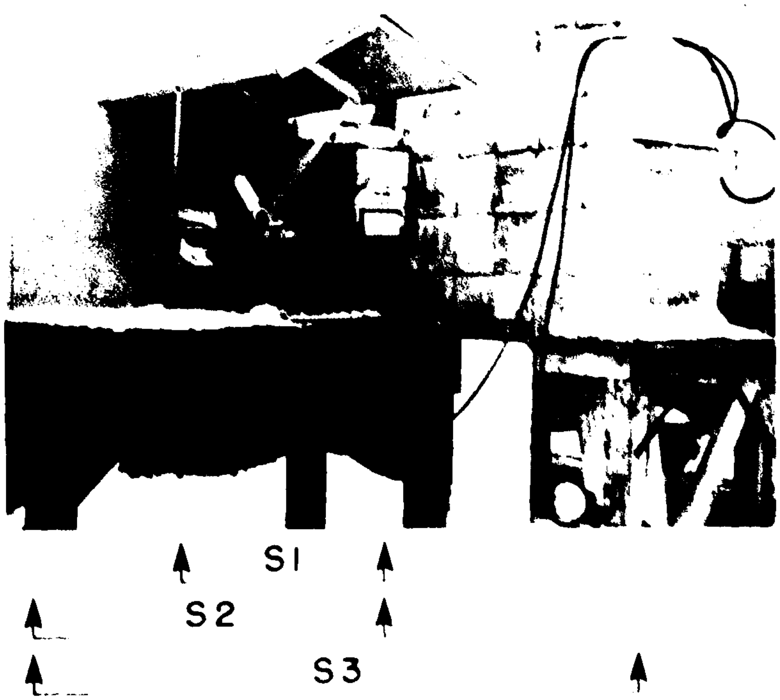

Figure 5B

The three shielding configurations which were employed.

by the PNR-4 Rem counter normalized with respect to the fission chamber counts obtained during the same counting period. The right-hand scale represents the dose-equivalent rate corresponding to the left-hand scale (conversion factor 0.149) and is based on the measured net response (100 cpm $\equiv$ 5.93 $\pm$ 0.19 mrem/hr.) of the PNR-4 to a Pu-Be source of known output and on the calibration factor of the fission chamber ($2.51 \times 10^5 \equiv 10^{10}$ n/sec into 4π). Techniques by which these factors were determined will be described in a future report.

Apart from some measurements which were made at locations whose direct view of the target was obstructed by the main L-shaped shielding wall near the target, such as those at E6 and F6, the majority of the points plotted in Figure 4 appear to fall into two relatively distinct groups such that the points in each group are distributed about, or conform closely to, an identifiably separate trend line. The two suggested trend lines, drawn through the origin, have been labelled I and II. Thus for each of the two groups of points the dose rate varies approximately inversely as the square of the distance from the target, but a different apparent source strength is indicated for the two cases, as evidenced by the $\sim$ 24% difference in the slopes of the lines I and II. This difference in the dose-distance dependence between the two groups of points is due to a number of factors, such as the auxilliary cement-block shielding near the target, the main shielding wall, the uneven terrain (particularly at back angles south of the target), and the (small) angular dependence of the output from the target. While a distinct demarkation between the regions where the measured dose rates follow one or other of the apparent trend lines is not to be expected, an appraisal of the dose rates at certain grid points in relation to the locations of these points with respect to the target can suggest a general basis for the difference in the trends which were observed. The following observations can be made:

i) The measurements made at those grid points directly ahead of the target, C5, D5, E5 and F5, all lie close to the lower trend line II. In this case the shielding wall, while not obstructing a direct view of the target, acts to remove essentially half of those neutrons which would normally be expected to scatter from the ground into the detector, as well as a significant fraction of those neutrons which form the skyshine component. In addition very few neutrons reflected from the wall or from the auxillary shielding near the target can be expected to reach the detector at any of these positions.

ii) The measurements at grid points G4 and G3, at $\sim 90°$ to the target, also conform to the trend of line II. Since the output from the target at this angle is expected to be no more than 6% less than that at 0°, and also because the neutrons detected at these points would include those reflected from the auxillary shielding near the target and from the wall, as well as the usual ground-scattered and skyshine components, it must be concluded that the low dose-rates at these points is mainly due to a reduced output from the target at this angle. A reduction in the neutron flux at 90° could occur because the neutrons are emitted in a direction essentially parallel to the plane of the target and can be absorbed or scattered in the target backing, in the cooling water, or in the target cap itself.

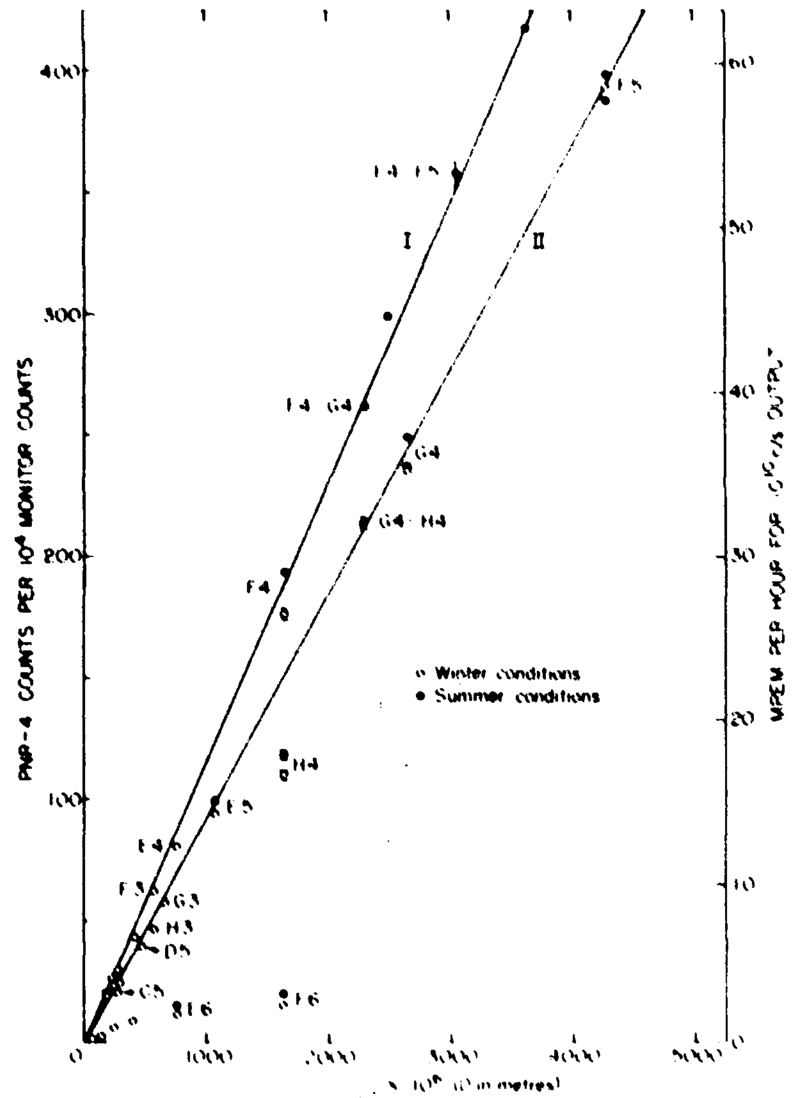

Figure 4

Responses of the PNR-4 Rem Counter at various of the grid points versus the inverse square of the distance of the particular grid point from the unshielded target. The two relatively distinct groups into which the measurements fall are indicated by the arbitrary trend lines labelled I and II. The plotted points labelled F4–F5 etc. refer to measurements made midway between the two grid points. The two unlabelled points above and below F4–F5 refer to locations at 2/3 and 1/3 of the distance between F4 and F5 respectively, as measured from F4.

iii) The measurement made at grid point H4 lies below trend line II by a significant amount. This point represents the largest backward angle ($\sim 130°$) at which any of the measurements were made and, as such, would be the point at which any effects of the non-isotropic output from the target would be most likely to be observed. In addition, the direct line-of-sight from the target to this point passes very close to the large oil-filled tank containing the isolation transformer and high-voltage power supply associated with the neutron generator in Building T1, and hence neutron absorption or scattering by the tank could reduce the air- or ground-scattered flux incident on the detector at this point, and absorption by the building itself could reduce the direct flux.

iv) Those dose-rate measurements which appear to follow trend line I were made at points within the forward quadrant, in a direction away from the shielding wall. At these points the major portion of the incident neutron flux, composed of the direct and the air- and ground-scattered components, would not be expected to be significantly affected by the presence of the wall. In addition, while these points were not equally accessible to neutrons reflected from the main wall, they all had an unobstructed view of the auxilliary cement-block shield between the target and the wall. This shield was only about one metre away from the target and would be a significant source of scattered neutrons.

Thus, in summary, the neutron flux described by trend line I, which is characteristic of a region in the forward quadrant away from the wall, is composed of direct and air- and ground-scattered components, together with a component reflected mainly from auxilliary shielding near the target. The reduced flux described by trend line II, on the other hand, is characteristic of two different regions where different factors contribute independently to produce apparently similar intensity distributions. Thus in the direction around 0° the main shielding wall reduces the ground-scattered and skyshine components, and neutrons scattered from shielding near the target are absorbed by this wall, with the result that the flux in this direction is smaller than that described by trend line I but contains a larger proportion of the direct flux. In the other region around 90° the flux is composed of the usual direct and scattered components characteristic of trend line I, but the intensity is smaller because the output from the target in this direction is reduced by absorption and scattering in the target itself. At backward angles, greater than about 120°, effects of the non-isotropy of the output and other factors combine to cause the flux to become smaller than that suggested by trend line II.

3.2 Derived Dose Equivalent of the Output of the Generator

From the slopes of the two lines I and II drawn in Figure 4, dose-equivalent factors of 60.4×10^{-6} and 48.3×10^{-6} mrem/n/cm^2 respectively can be derived as applicable to the output of the neutron generator in the regions characterized

by the two trend lines. The values derived for these factors depend in particular on calibration of the Rem counter with respect to the calculated dose-equivalent factor ($\sim$41.1 × 10^{-6} mrem/n/cm^2) of a standard Pu-Be source (average E_n 4.2 - 4.3 MeV) of known output. For 14-MeV neutrons a dose-equivalent factor of 57.8 × 10^{-6} mrem/n/cm^2 has been recommended (3), which corresponds closely with that obtained from the slope of trend line I. However detailed comparison of these factors is not meaningful for two reasons: the assumed flux of 10^{10} n/s from the target is augmented by an unknown amount by scattered neutrons which are also incident on the detector, and the Eberline PNR-4 Rem counter does not provide the appropriate relative dose-equivalent response for the different neutron energies characteristic of the direct and scattered components. Thus, on the basis of the response curve published in the technical manual which accompanies the Rem counter (4), it is apparent that the measured response approximates the desired dose-equivalent curve only in the range of about 400 keV to 3-4 MeV, being too high below this range and too low above. At 10 MeV the response curve appears to be about 35% too low and falling rapidly; thus at 14 MeV the discrepancy could be expected to be even greater. An energy response of this nature appears to be typical of those neutron survey instruments which are available commercially (5).

The previous survey (1) which was carried out employed a different type of Rem counter, SNOOPY, which had similar response-characteristic deficiencies to those exhibited by the PNR-4, and it is of interest to compare the dose-equivalent rates which were measured at some common locations in the two surveys. Such a comparison is given in the following table:

LOCATION	DOSE-RATE EQUIVALENT		mrem/hour
	Summer Conditions		Winter Conditions
	SNOOPY	PNR-4	PNR-4
At gate of perimeter fence	0.3-0.5		0.36 ± 0.02
Railway fence at position of minimum distance to target	1.5-1.7		2.03 ± 0.07
Outside entrance to Bldg. 14		0.27 ± 0.01	0.20 ± 0.02
Detector facing target	0.2-0.3		
Detector facing up	0.1-0.2		

Thus the dose rates measured by the two instruments were similar, but precise quantitative comparison is not warranted since the dose rates measured with SNOOPY were obtained by visually estimating the average deflection of the fluctuating needle of the count-rate meter, whereas the output of the PNR-4 was recorded by means of a scaler. It is apparent, however, that the measurements made with the PNR-4 at the entrance to Building 14 at different times of year suggest that there is a significant reduction in the dose rate under winter conditions when the surrounding area is covered with snow. This point will be discussed later. The errors quoted for the PNR-4 measurements in the above table are statistical, being based on the number of counts obtained, and are not estimates of the accuracy of the dose rates themselves.

4. EFFECTS OF LOCAL SHIELDING NEAR THE TARGET

4.1 Shielding Configurations Employed

A number of different local shielding arrangements near the target were investigated in order to determine the most effective means of reducing the dose rate at the specific locations identified by the AECB.

Three shielding configurations were employed as indicated in Figure 3B:

S1 A 4 × 4 array of cement blocks, each 19 cm × 14 cm × 40 cm, located between the target and the railway tracks at a distance of 30.5 cm from the centre of the target.

S2 A similar 4 × 5 array of cement blocks at a distance of 30.7 cm from the target, with three 18-cm-thick boxes of paraffin on the side of the array away from the target and these surmounted by two cement blocks. This configuration takes advantage of the fact that compound shielding with heavier elements located towards the incident neutron beam has been shown to constitute the preferred elemental distribution (6).

S3 The same arrangement as S2, with the addition of a cement block 43 cm square and 31 cm thick, with a centrally located hole 30.5 cm in diameter, which was placed symmetrically about the target, with two of the standard cement blocks on top. In this case the shielding above the target subtended a solid angle of approximately 0.7-0.8 π steradians.

4.2 General Effects of the Various Shielding Configurations

The dose-rate measurements which were made with these different shielding arrangements are all plotted in Figure 5 versus the inverse square of the distance of the particular grid point from the target. Both the normalized PNR-4 counts obtained at each of the grid points and the corresponding dose equivalents are indicated on the axis of ordinates. The straight lines

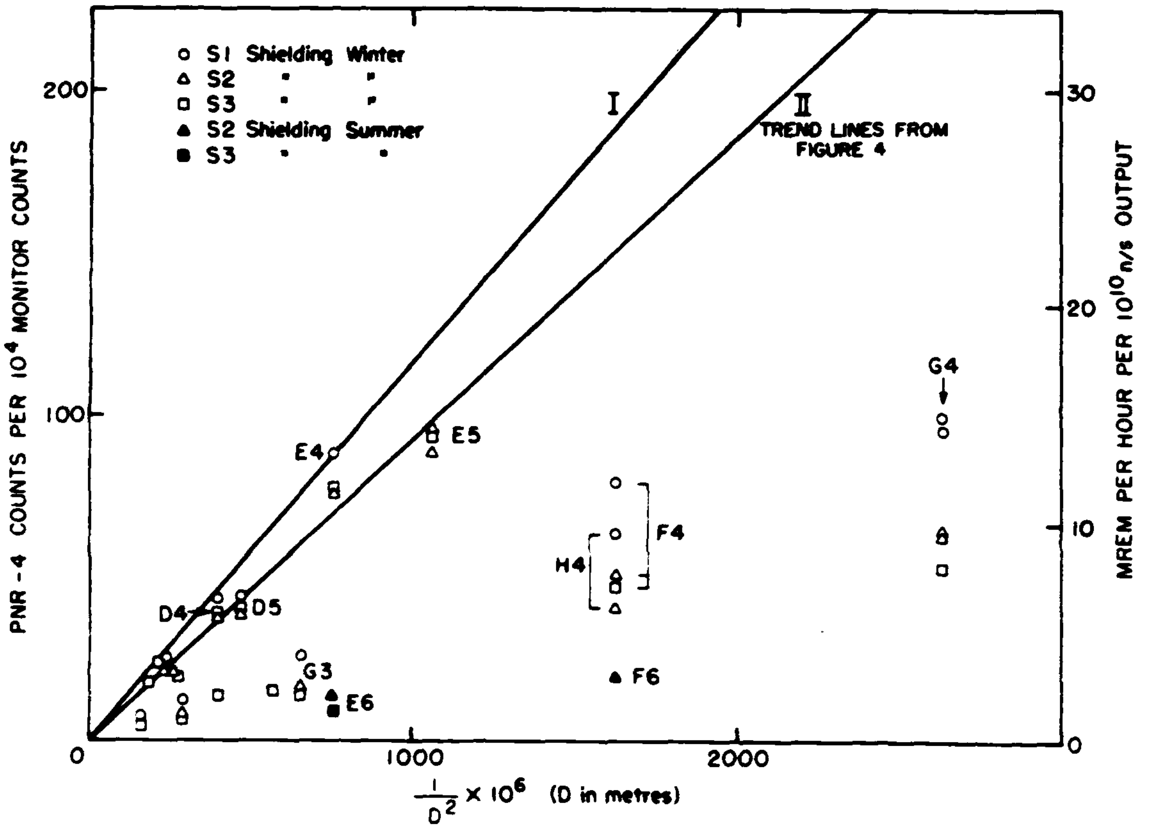

Figure 5

Response of the PNR-4 Rem Counter at various of the grid points for the case of different shielding arrangements near the target. The straight lines which have been drawn represent the two trends of the dependence of dose rate with distance which were evident in the unshielded case as indicated in Figure 4.

which have been drawn in Figure 5 are identical with those drawn in Figure 4 to represent the two trends of the dependence of dose rate with distance which were evident in the unshielded case.

Those points plotted in Figure 5 which appear to follow the trends suggested by the lines which have been drawn represent measurements made at grid points whose direct view of the target was not obstructed by the various shielding structures erected near the target. Thus, on the basis that the apparent total neutron output from the target, as determined by the fission chamber, was not affected by scattered neutrons, it appears that the dose rate measured at such grid points was not significantly influenced by the added shielding. The apparent anomaly presented by the measurements at grid point E4, wherein shielding arrangements S2 and S3 slightly reduced the dose at this point compared with that measured in the unshielded case while arrangement S1 had no such effect, can be accounted for by the fact that the 4 × 5 array of cement blocks in configurations S2 and S3 extended about 8 cm further forward of the target than did the 4 × 4 array in the S1 configuration. Thus, for shielding configurations S2 and S3, the line joining the target to grid point E4 (and by extension to C3) approximately defines the transition between that region south of the target which was shadowed from the target and the area forward of the target which was not.

In the case of those grid points, such as G3, G4, F4, whose direct view of the target was completely blocked by the added shielding, the degree to which the dose rate was reduced was a function of the particular shielding configuration, as indicated by the references to certain specific grid points in Figure 5. In general, the S2 configuration was markedly superior to S1, while S3 produced only a marginal improvement over S2.

4.3 Dose-Rate Reduction Along Railway Fence

As stated previously, one of the major points of concern to the AECB was the relatively high dose rate along the perimeter fence bordering the railway right-of-way which was produced by the unshielded target. Figure 6 is a linear plot of the unshielded and shielded dose rates along this fence, as measured at grid points A1 to H1. These measurements are not contained in the data plotted in Figure 4 and Figure 5, since such a presentation would be obscure and would not facilitate a convenient or direct visual comparison of the pertinent points. As can be seen from Figure 6, the shielding introduced between the target and the fence reduces the maximum dose rate by about a factor of 3 to a level of about 0.7 mrem/hr. It would appear that any further significant reduction of the dose rate along the fence could only be attained by a considerable increase in the amount of shielding over that already in place.

4.4 Measurements at Building 14

Building 14 is located about 130 m from the target of the neutron generator and is shielded from the direct neutron flux by the main L-shaped concrete-block wall near the target; thus the neutron flux incident on the

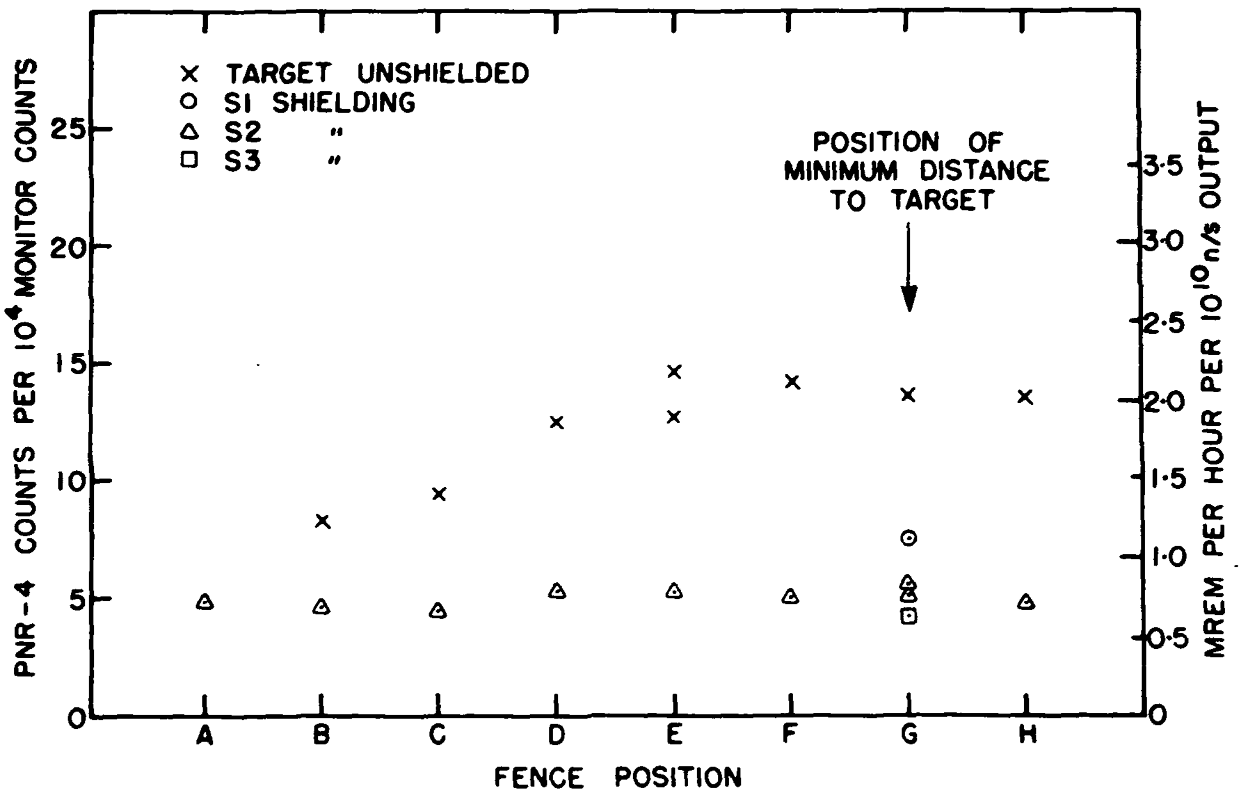

Figure 6

Response of the PNR-4 Rem Counter at locations along the perimeter fence bordering the railway right-of-way.

building will consist mainly of skyshine and ground-scattered components. As stated previously, the AECB was concerned about the dose rate at the entrance to this building, as well as that inside the building since, on the basis of the previous survey (1), an integrated yearly exposure considerably greater than 5 mrem would result if the neutron generator was operated, even at a reduced output of $1/3 \times 10^{10}$ n/s, for a period approaching the total number of hours (20 hours per week for 50 weeks) permitted by the operating licence (A18/77). Thus the effect, adverse or otherwise, of shielding added near the target on the dose rate at Building 14 was of interest to the AECB.

The measurements made at Building 14 are summarized in the following table, where the dose rates are normalized to an output of 10^{10} n/s from the target:

TARGET SHIELDING CONFIGURATION	DOSE-RATE EQUIVALENT mrem/hour	
	SUMMER CONDITIONS	WINTER CONDITIONS
Unshielded towards railway	0.28 ± 0.01	
	0.26 ± 0.01	
	Av.0.27 ± 0.01	0.20 ± 0.02
S2 shielding	0.25 ± 0.01	
S3 shielding	0.18 ± 0.01	

The measurements listed in the table as being made under "summer conditions" were actually carried out in April-May (1978) after the snow cover had disappeared and as the shielding structure near the target was being dismantled in stages. In this case the measurements made with the target unshielded towards the railway (i.e. the added shielding removed completely) can be compared with those made with SNOOPY under similar conditions (i.e. absence of snow cover) in the earlier survey (1) and which have been discussed previously. It is apparent from the dose-equivalent rates under summer conditions quoted in the above table that the shielding configuration S2 had very little effect on the dose rate at Building 14 as compared with the unshielded case. It was only when shielding was introduced above the target, as was the case for the S3 shielding configuration, that a significant reduction in the dose rate occurred, the obvious mechanism being a reduction in the skyshine component. It should be noted, however, that the dose rate obtained with the S3 configuration under summer conditions was almost the same as that measured under winter conditions without any additional shielding

near the target. In the latter instance it would appear that the snow cover acts to reduce the ground-scattered component incident on Building 14. Further examples of the effect of the snow cover will be discussed below.

5. THE EFFECTS OF SNOW-COVERED TERRAIN ON DOSE RATES MEASURED AT OPEN-FIELD LOCATIONS

Different dose rates were measured at Building 14 under summer and winter conditions for the same total neutron output rate from the target, as discussed above, and this difference was attributed to the effects of snow cover in reducing the ground-scattered flux. In this case it was possible to observe the difference in dose rate clearly because only the skyshine and ground-scattered flux were incident on the building, the direct flux being blocked by the L-shaped shielding wall near the target. While the more-intense direct flux would be expected to mask minor changes in the air- or ground-scattered components, it is possible that small seasonal changes in dose rate were observed in some measurements at grid locations which were in direct view of the target, as can be ascertained by inspection of Figure 4 (e.g. locations E5, F4, G4, H4). More significant seasonal diferences, however, were observed for points such as E6 and F6, which were shielded from the direct neutron flux by the main wall and which were much closer to the target than had been the case for Building 14. The dose rates measured at these two locations under various conditions, for a neutron output of 10^{10} n/s, are summarized in the following table:

TARGET SHIELDING CONFIGURATION	DOSE-RATE EQUIVALENT mrem/hour			
	E6		F6	
	Summer	Winter	Summer	Winter
Unshielded towards railway	2.24 ± 0.04	1.73 ± 0.09	3.01 ± 0.06	2.28 ± 0.10
S2	2.04 ± 0.03		2.95 ± 0.06	
S3	1.36 ± 0.03			
	1.35 ± 0.02			

Thus, for the case of no added shielding near the target, the dose rates at the two points are each about 23-24% smaller under winter conditions than in the summer, and these winter dose rates are also smaller than those measured in the summer with the S2 shielding in place. The above results are thus similar to those obtained at Building 14, but are statistically more significant because of the larger neutron flux available at the E6 and F6 locations.

6. RESPONSE CHARACTERISTICS OF THE EBERLINE PNR-4 REM COUNTER

As stated previously, the calibration of the Rem counter was based on its response to a standard Pu-Be source of known output, this response being related to the calculated dose-equivalent factor for the source. The response of the Rem counter, however, approximates the desired dose-equivalent curve only over a relatively small energy range (4), from 400 keV to 3-4 MeV, and thus, as pointed out, dose-rate measurements at locations where the direct 14-MeV flux is incident on the counter would be expected to be in error by a considerable amount.

A meaningful calibration of the response of the detector at 14-MeV, based on the known output from the target as determined by the fission chamber and the recommended (3) dose-equivalent factor applicable to 14-MeV neutrons, was not feasible at any of the unshielded locations at which measurements were made because of the unknown contribution of the skyshine and ground-scattered components. It was possible, however, to compare the dose rates indicated by the PNR-4 Rem counter at a number of locations with those determined at the same time by means of an NE-213 scintillation detector (7). In the latter case the neutron spectrum above 0.5 MeV was determined by proton-recoil spectroscopy and integrated against the ANSI (3) fluence-to-biological-dose conversion factors. Comparisons were made both at unshielded locations where the 14-MeV flux from the target would be predominant, and also at locations where a direct view of the target was blocked by the main shielding wall and where the air- and ground-scattered flux would consequently be expected to make the major contribution to the measured dose rate.

The results of these measurements, normalized to a neutron output of 10^{10} n/s, are summarized in the following table; also included are values for the average neutron energy as determined in each case by the recoil proton spectrometer, as well as the expected dose rates for a pure 14-MeV flux calculated on the basis of the recommended (3) dose equivalent factor of 57.8×10^{-6} mrem/n/cm^2 for 14-MeV neutrons:

Location	Distance to Target (m)	Dose-Rate Equivalent mrem/hour			Average E_n MeV	Ratio Proton recoil / PNR-4
		PNR-4	Proton recoil	Calculated		
F5	15.35	59.4 ± 0.9	98.1	70.3	12.53	1.65
K5	30.70	14.8 ± 0.2	22.8	17.6	12.13	1.54
F4-F5 *	18.18	53.3 ± 0.8	78.[illegible]	50.1	11.59	1.48
F6	24.82	2.95 ± 0.06	1.[illegible]3	--	3.80	0.586
K6	36.37	2.24 ± 0.04	1.42	--	3.66	0.634

* Halfway between grid points F4 and F5, at about 32° from target.

† S2 shielding in place; for all others target unshielded towards railway.

Thus at the first three locations listed in the table, all of which had an unobstructed view of the target, the dose rates derived from the recoil spectrometer measurements are from 48% to 65% higher than those indicated by the PNR-4 and reflect, in part, the inadequate dose-equivalent response of the Rem counter to high-energy neutrons, as discussed previously. The fact that the recoil-proton measurements give dose rates which are also considerably higher than those calculated on the basis of a 14-MeV neutron output of 10^{10} n/s from the target can be attributed mainly to the contribution of scattered neutrons. This conclusion is supported by the fact that the greatest difference (57%) between the calculated dose rates and those measured by proton recoil occurs for the F4-F5 location. This particular location is the only one of the three which was within sight of the auxilliary shielding wall near the target, and this wall would be expected to be a significant source of scattered neutrons, as already pointed out. The lower average neutron energy, 11.59 MeV, which was measured at this location, as compared with that measured at F5 or K5, is also consistent with this expectation. Thus the scattered-neutron component makes up an important fraction of the total number of neutrons which were detected by the recoil spectrometer at this location. The fact that, of the PNR-4 measurements, the one made at this same location deviates least (6%) from the calculated dose rate can be accounted for on the same basis. In this instance the greater sensitivity of the PNR-4 to the lower-energy flux of scattered neutrons partially compensates for its relative insensitivity to the higher-energy direct component.

At locations F6 and E6, which are behind the main shielding wall and where the average incident neutron energy is less than 4 MeV, the dose rates measured by the Rem counter are higher than those based on the recoil proton spectrum. At such locations it might be expected that the PNR-4 measurements would be more reliable than those made at unshielded locations, since calibration of the Rem counter was based on the known output of a standard Pu-Be source whose average neutron energy of $\sim$ 4.2 MeV is not greatly different from that to be found at the shielded locations where these measurements were made. The higher dose rate indicated by the Rem counter as compared with that obtained by the recoil proton technique can be attributed both to the enhanced response of the PNR-4 below 400 keV, assuming the measured spectrum is weighted relatively more in this region than is the Pu-Be spectrum, and to the 500-keV detection threshold of the recoil proton spectrometer.

7. SUMMARY

A field survey has been carried out to assess the effectiveness of various forms of shielding around the target of the neutron generator in reducing the dose rate at selected locations on the DREO site. Measurements at specific locations of interest to the AECB showed that varying degrees of additional protection could be attained, depending on location. Thus, along the fence bordering the railway right-of-way, the most effective shielding arrangement which was employed, S3, reduced the dose rate by only a factor of 3 from that produced by the unshielded target. It was apparent that any further significant reduction in dose rate would require the installation of considerable additional shielding. At locations which were already shielded by the main L-shaped wall near the target, such as Building 14, it was possible to make a marginally significant reduction (50%) in the dose rate only when shielding was introduced above the target. At such locations the beneficial effects of snow cover in reducing the dose rate, through a reduction of the ground-scattered component, were also observed; thus at Building 14 the winter dose rate without additional shielding near the target approximated that observed in summer with the maximum S3 shielding in place.

The results of this survey lead to the conclusion that the most effective shadow shield which was employed would probably satisfy AECB requirements so far as the dose-rate along the railway fence was concerned, the AECB being prepared to accept the measured dose rate as being as low as reasonably achievable (ALARA), considering the low occupancy factor. On the other hand, it can also be concluded that the marginal reduction in dose rate which was produced at Building 14 by means of shielding added above the target was indicative that even a more substantial shield of the same nature would not be totally acceptable under the AECB guidelines to permit continued operation of the generator for the full number of hours specified in the licence. Thus it can be surmised that AECB requirements as regards the yearly dose at Building 14

could only be met either by construction of a massive concrete shield which surround the target practically entirely, or else by monitoring factors related to the neutron output in order to obtain a measure of the cumulative dose inside Building 14, and being prepared to cease operations for the year once the total had reached 5 mrem.

The practical utility of the PNR-4 Rem Counter for carrying out a meaningful quantitative survey can be questioned as a result of experience which has been gained in the use of the instrument in the field. While the instrument itself can apparently be calibrated very precisely and consistently with Pu-Be neutrons, its inadequate relative response to a different neutron spectrum suggests that dose-rate measurements made with the instrument in a fast-neutron flux of arbitrary spectral composition can be relied upon to no more than a factor of two.

8. ACKNOWLEDGEMENTS

The authors wish to thank Mr. J.R.W. Boyle for his assistance in laying out the survey grid, Mr. L.P. Rushton for assisting in some of the measurements, and Mr. F.G. Strain for operating the neutron generator during calibration of the fission detector.

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1 ORIGINATING ACTIVITY Defence Research Establishment Ottawa National Defence Headquarters Ottawa, Ontario, Canada K1A 0Z4	2a DOCUMENT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 DOCUMENT TITLE
The Effectiveness of Various Local Shielding Arrangements Erected near the Target of the DREO Neutron Generator in Reducing the Biological Hazard at Specific Locations on the DREO Site.

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Note.

5 AUTHOR(S) (Last name, first name, middle initial)

Johnson, F. Allan and Brisson, Jean-Roch

6 DOCUMENT DATE September 1979	7a TOTAL NO OF PAGES 20	7b NO OF REFS 17

8a. PROJECT OR GRANT NO 11A00	9a ORIGINATOR'S DOCUMENT NUMBER(S) 79-20
8b CONTRACT NO	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10 DISTRIBUTION STATEMENT

Distribution unlimited

11 SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY

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The effectiveness of various forms of shielding near the target of the neutron generator in reducing the dose rate at specific locations on the DREO site has been investigated. It would appear possible to satisfy AECB requirements so far as reducing the dose rate along the perimeter fence bordering the railway right-of-way is concerned, but substantial additional shielding would be required to reduce the dose rate significantly at the nearest occupied building, Building 14. In the latter case, to take advantage of the maximum operating hours permitted by the licence, AECB requirements could be met only by construction of a massive shield around the target, otherwise the cumulative dose inside Building 14 could be monitored and operations terminated when the total dose reached the permitted yearly limit for non-atomic workers.

DSIS
77-505

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Fast neutrons Neutron flux Neutron scattering Neutron shielding Rem counters Dose-equivalent rate Neutron detectors

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by

F.A. JOHNSON AND J.R. BRISSON

E R R A T A   S H E E T

Figure 3A and figure 3B photographs should by interchanged but the captions should remain as they are.

Page 6, line 6 should read "the fission chamber (2.51×10^5 cpm $\equiv$ 10^{10} n/sec into 4π). Techniques by which ..."

Page 17, table should be F6^{+} and not just F6.